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DEVELOPMENT OF AN ADAPTIVE SUPPORT DEVICE FOR THE PREVENTION OF BEDSORES

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ABSTRACT

An approach on the development of an adaptive support device to prevent bedsores is presented in this paper. For the bionic development process of the mechatronic system the human skin with its special three-dimensional geometry of the boarding surfaces of the layers as well as the distribution of biological sensors and actuators is particularly interesting as the source of inspiration for the technical implementation. The support system developed enables the detection of critical pressure values as well as the dedicated stimulation of susceptible skin areas and it can be used in a system for pressure ulcer prevention.

Index Terms - Bedsore, pressure ulcer prevention, bionics, human skin, tactile sensor array, shear force detection

1. INTRODUCTION

Constant long-time compression of the skin may cause bedsores especially in case of immobile hospital patients or bedridden people. Even with optimal quality of care painful skin lesions can occur that range from simple reddened skin to open pressure ulcers. The high prevalence figures and the associated economic, ecological and social effects indicate the need of improved prevention systems.

Especially shear forces in addition to pressure loads are a crucial factor to intrigue the development of bedsores [1] and [2]. For the quantification of the risk of pressure ulcer development the relation of the interface pressure (pressure between top of the skin and the support surface) to the capillary pressure inside the human tissue is important to know. Recent studies confirm a qualitative correlation, but they also show that this quantitative correlation is low [3].

However, previous plane sensor mats, which are used to measure the interface pressure, can determine only two-dimensional pressure distributions. That's why it is important to develop a technical system that enables the determination of quantity and direction of force, too.

Currently used products and prevention aid systems for the realization of various types of support treatments each have disadvantages, such as disorientation or non-existing mobilization of the patient. For that reason especially a higher adaptivity for the consideration of the individual patient situation plays an important role in the novel prevention system to be developed. This will require the following characteristic features:

- measurement of extrinsic factors: pressure and time, shear, temperature, humidity,
- dedicated compliance, minimization of shear forces and basal stimulation,
- adjustable stiffness and flexibility,
- qualities for special applications (e. g. radioscopy in the surgical field).

2. MATERIAL AND METHODS

2.1. Bionic approach

Inspired by the largest human sense organ, the human skin, approaches for the design of a flat and flexible sensor-actuator system are made. Especially the human skin with its special features and huge sensor and actuator capabilities is very interesting as source of ideas for the bionic process respectively its technical implementation.

The basic construction of the skin and its mechanical properties are analyzed in detail and abstracted for a FEM simulation. From the numerical investigation of the influence of different parameters, principles for the technical realization can be derived.

2.2. Investigation and FEM-analysis of the multi-layered human skin

The detection of mechanical stimulation is influenced by types and distribution of tactile receptors, by tissue properties as well as by the three-dimensional geometry of the boundary surfaces of skin layers (papillae).

The relevant layers of the skin are the epidermis (epithelial part) and the dermis (connective tissue). The wavelike papilla is originating from the stiffer layer of the bottom. The papillary layer adjoins directly to the epidermis and is coupled with it via connective tissue. Shapes and quantity of papillae depend on the local mechanical requirements.

The epidermis consists of many different layers of squamous epithel cells, which are located closely beside each other and are connected via elastic desmosoms. It differs in dead (1) and regeneration (3) layer (fig. 1). Between those two strata the epithelial layer of hornification is situated. The papillary dermis includes a lot of lymphatic and blood vessels. The blood vessels create a loop in each papilla and can change their stiffness [4].

For purposes of modelling, the mechanical material properties and the Young's modulus of the separate layers are taken from relevant studies [5].

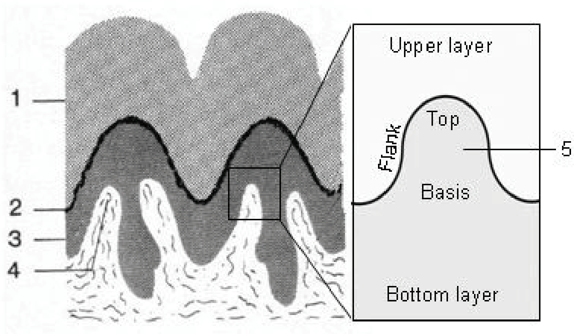

Figure 1: *Abstraction of the skin-model with epidermis and papillae dermis on the fingertip [6]: 1 – Stratum corneum; 2 – Stratum granulosum; 3 – Stratum spinosum; 4 – Stratum papillae with connective tissue; 5 - Papilla.*

The decomposition of the force vector which acts on the skin surface, and the value and position of this force in the papillary dermis can be determined with analytical calculations. At first, the analytic models are calculated by the finite elements method under different loading (normal and tangential forces) and with variable mechanical parameters like the Young's modulus, geometry of boundary surface and flank angle of papilla. The two-dimensional model consists of the periodic papillae and the layers which are relevant for the force transmission.

3. RESULTS

3.1. Investigation and FEM-analysis of the multi-layered human skin

From the results of calculation the force distribution on the boundary surface between both layers and a resulting different deformation behavior can be estimated, as shown in fig. 2.

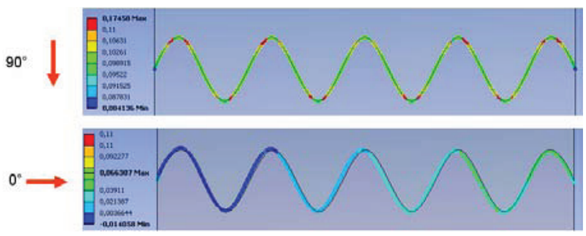

Figure 2: *FEM-Simulation - illustration of the contact pressure distribution as a function of force direction*

The results of the model-based investigations show, that the following aspects of complex design of the skin are relevant for the technical development:

- multiple layers,
- the different and variable stiffness of individual layers,
- the wavelike interface layer between epidermis and dermis
- the special arrangement of the receptors,
- sensor-actuator integration and interaction.

3.2. Demonstration model from silicone

A demonstration model made of silicone is built in order to verify the derived technical principles and expand the know-how regarding the manufacturing of plane compliant structures.

The multi-part prototype, with its integrated actuator and sensor technologies, is initially designed as an air chamber system, and has a pneumatic actuator. The sensor technology was realized via contact sensors. In order to reduce the number of cables and wires, the top of the structure is designed of conductive silicone as the ground (fig. 3).

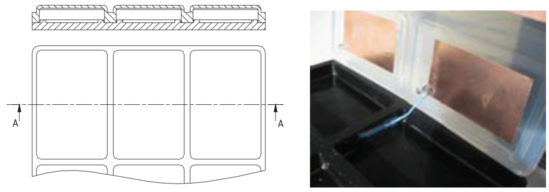

Figure 3: *Conception, construction and assembly of the demonstration model with sensors from conductive silicone*

On the basis of systematic testing, the functioning of a mechatronic anti decubitus support system and the effect of different parameters influences are investigated. Figure 4 shows the experimental setup.

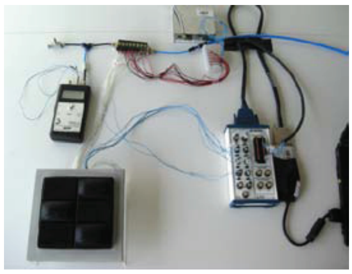

Figure 4: *Programming, controlling and testing of the demonstration model with LabVIEW*

With the demonstration model passive (without sensors, fig. 5) as well as active (with sensors, fig. 6) prevention treatments can be realized.

Figure 5: *Passive prevention treatments*

In conclusion the demonstration model has the following multifunctional characteristics:

- aid for the estimation of the risk to develop a pressure ulcer by measuring the pressure distribution and other factors,
- efficient adjustment to the patient by pressure controlled stiffness, regardless of position and weight,
- minimization of pressure, friction and shear forces through the realization of several support types,
- dedicated stimulation of the skin blood flow of susceptible skin areas.

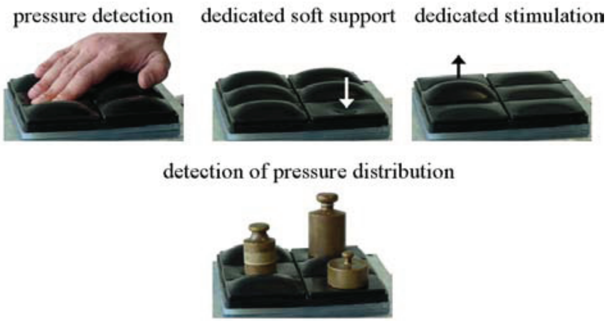

Figure 6: *Active prevention treatments*

4. DISCUSSION

The adaptive support system enables many features, which conventional products don't offer. It can already be used as a prototypical simple and low-cost anti decubitus support system.

In the further development, the sensors for the detection of shear forces, the overall design of the support system and a more accurate adjustment of sensors and actuators have to be implemented. Concepts already exist for this purpose.

For the mechanical determination of normal and shear forces tactile plane sensors according to the extrinsic active principle are state of the art. In this case the distinction of the applied force angle is enabled by the distortion of a deformation element which depends on the load case direction. An idea to simplify the measurement of shear force is the use of plane sensors according to intrinsic active principle.

5. CONCLUSIONS

A biomimetically oriented approach based on investigation and FEM-analysis of the human skin is presented in this work, in order to develop a novel adaptive support device with enhanced functions for the prevention of pressure ulcera. A supporting evaluation of pressure ulcer risk can be provided by the determination of the load situation acting on the skin, especially by measuring shear forces.

The analysis of the state of the art and the consideration of abstracted biological principles result in a demonstrator made of silicone which can be used for the investigation of basic functions of support systems. Furthermore the realization of new properties, like an optimal distribution of pressure and a minimization of tangential forces and friction, can be implemented with the layered compliant structure. With the integrated sensor and actuator technologies the detection of the load direction as well as an efficient adjustment of the stiffness and therewith of the sensitivity is possible too.

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